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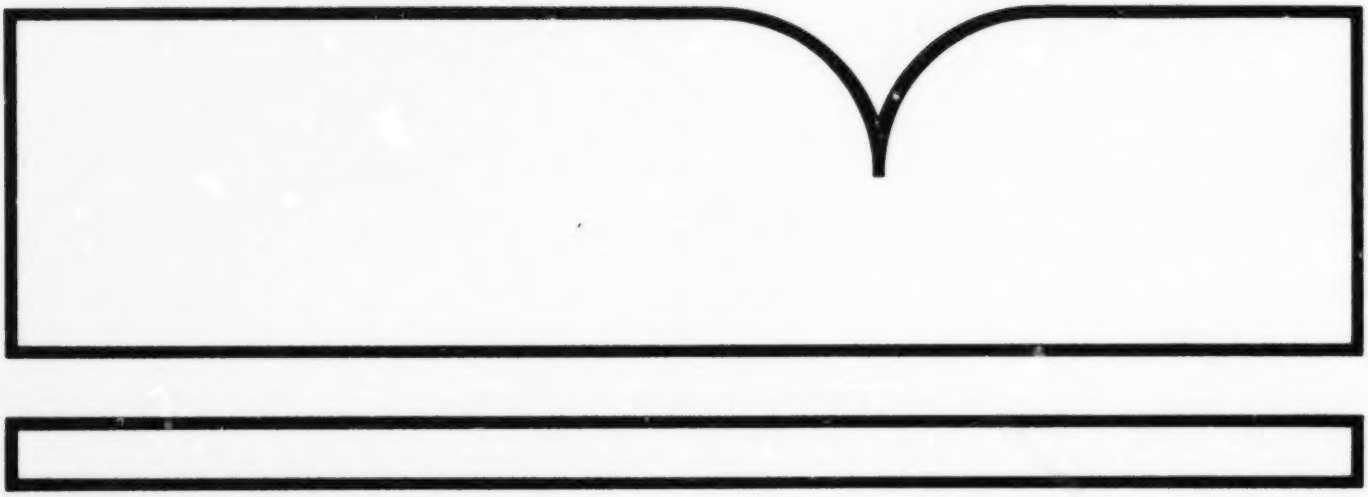

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Advances in Control Technology for Acid Deposition

by

G. B. Martin, J. H. Abbott, and L. E. Sparks
Air and Energy Engineering Research Laboratory
Research Triangle Park, NC 27711

Air and Energy Engineering Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

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16. ABSTRACT Causes and effects of acid deposition are the subject of widespread discussion both in the U. S. and Europe. Two major concerns are the acidification of lakes and streams, and forest damage. The proposed mechanism for acidification of lakes and streams is the deposition of acidic materials such as sulfate and nitrate. While forest damage mechanisms must be established, one current theory is that it is the result of oxidants formed in the atmosphere by reaction of nitrogen oxides (NOx) and hydrocarbons. These acidic materials are postulated to be formed in the atmosphere from precursors, principally sulfur dioxide (SO2), NOx, and hydrocarbons, emitted from automotive, industrial, and utility sources. Conventional methods for reducing SO2 emissions from coal-fired power plants include flue gas desulfurization, coal cleaning, and switching to lower sulfur fuel. Several emerging technologies may provide more cost effective control of SO2 and/or NOx. The EPA is actively developing two such technologies: Limestone Injection Multistage Burners (LIMB) and E-SOX. This paper summarizes the status of the technology and discusses planned research and development activities.

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G. B. Martin, J. H. Abbott, and L. E. Sparks
Air and Energy Engineering Research Laboratory
U.S Environmental Protection Agency
Research Triangle Park, NC

INTRODUCTION

The causes and effects of acid deposition are the subject of widespread discussion both in the U.S. and Europe. Two major concerns are the acidification of lakes and streams, and forest damage. The proposed mechanism for acidification of lakes and streams is the deposition of acidic materials such as sulfate ($SO_3^=$) and nitrate (NO_3^-). While forest damage mechanisms must be established, one current theory is that it is the result of oxidants formed in the atmosphere by reaction of nitrogen oxides (NO_x) and hydrocarbons. These acidic materials are postulated to be formed in the atmosphere from precursors, principally sulfur dioxide (SO_2), NO_x, and hydrocarbons, emitted from automotive, industrial, and utility sources.

Conventional methods for reducing SO_2 emissions from coal fired power plants include flue gas desulfurization (FGD), coal cleaning, and switching to lower sulfur fuel. Several emerging technologies may provide more cost effective control of SO_2 and/or NO_x. The EPA is actively developing two such technologies: Lime-

stone Injection Multistage Burners (LIMB) and E-SOX. This paper summarizes the status of the technology and discusses planned research and development activities.

BACKGROUND

Sulfur oxides (SO_x) and NO_x are two major pollutants resulting from the combustion of fuels. Coal fired utility boilers account for about 70 percent of the SO_x and 20-25 percent of the NO_x emissions in the U.S. For the 180,000 MW of coal fired boiler capacity east of the Mississippi River, this amounts to approximately 14.5 X 10^9 kg (16 million tons) of SO_2 and 3.63 to 4.54 X 10^9 kg (4-5 million tons) of NO_x emitted per year. (ref 1) Only about 10 percent of these boilers are subject to new source performance standard (NSPS) controls for SO_x and NO_x. Therefore to significantly reduce SO_x and NO_x requires a retrofit of controls to existing boilers which may have a remaining useful life of from 5 to 30 years. The vast majority of these are wall-fired and tangentially fired boilers.

The seriousness of the acid rain problem and the importance of various acid precursor sources are still under debate; however, control of SO_2 from utility boilers is a major element in all proposed strategies. In addition NO_x is increasingly being linked to forest damage mechanisms. Proposed reductions of SO_2 range from 4.54 to 10.88 X 10^9 kg/yr (5 to 12 million tons per year), and the issue of an NO_x offset is being debated.

The choice of emission control strategies will have a significant effect not only on the ability to achieve any mandated reduction but also on its cost to the Nation. The final decision on the technology mix will be based on the availability, specific performance, cost, and overall economic impact on the Nation, including socioeconomic factors such as displacement in the work force. Among the control technology options commercially available are coal switching, coal cleaning, and various types of flue gas desulfurization (FGD) systems. In addition, some early analyses indicated that a low capital cost technology would be attractive even at moderate SO_2 removal (e.g., 50 percent control). Although several approaches are being developed, none of the potential low cost alternatives have been demonstrated. One such rapidly emerging technology is LIMB which is based on the injection of sorbents into the boiler for direct capture of SO_2 from the combustion gases. Another is the E-SOX process which has recently been developed by the EPA. Each of these technologies is discussed below.

LIMESTONE INJECTION MULTISTAGE BURNERS (LIMB)

There is a considerable body of background information on sulfur capture by injection of sorbents into a conventional boiler. The information includes the experience in the U.S. with sorbent injection through a number of boilers in the late 1960's and early 1970's, some current experience in Germany on both brown coal boilers and other small-scale experimental facilities, and, finally, EPA testing using the distributed mixing low-NO_x burner with

sorbent injection in a pilot-scale facility. These efforts were summarized by the authors at a recent symposium. (ref 2)

Structure of the Program

This background information was used in structuring the LIMB program, which was initiated by the EPA in 1981. LIMB combines sorbent injection for SO_x control with low-NO_x burners for NO_x control. Low-NO_x burners of various designs have been developed by both EPA and private industry and are capable of retrofit applications. SO_x control by sorbent injection is an emerging technology which has been developed by the EPA. The reaction of SO_x with sorbents (i.e., limestone and other alkaline solids) is well known under proper conditions (e.g., wet FGD). LIMB is based on the injection of a sorbent directly into the furnace and its subsequent reaction with gas-phase SO_2 to form a dry calcium sulfate. The amount of SO_2 that can be captured is dependent on the type and amount of sorbent, its mixing with combustion gases and fly ash in the furnace, and its thermal history. The relative simplicity of the technology lends itself to a relatively low cost retrofit on a wide variety of systems. A schematic of the process with various sorbent injection options is shown in Figure 1. The program has been structured to give the best probability of achieving the stated goals of moderate SO_x and NO_x control (50-60 percent) at low cost with applicability to the major portion of the existing boiler population. A secondary objective is to improve the SO_x removal efficiency to 70-90 percent for new sources. To achieve this, work

has been concentrated in the four major areas discussed below.

Generic R&D. The program is centered around generic R&D to provide a complete understanding of the important factors in sulfur capture by sorbents. This work is performed in experimental systems which simulate conditions in a boiler without being subject to hardware constraints. The generic R&D is currently concentrated in improved sorbent activity for retrofit systems, although it also has application to new systems.

Prototype Testing. The results of the small-scale generic R&D must be scaled up to practical systems. As an intermediate step prior to a demonstration, prototype testing is carried out in large experimental systems. In addition small boilers may be used to provide R&D data on scaleup, operability, and reliability.

Wall-fired Boilers Demonstration. Wall-fired boilers, one of the two major types of boilers, are sold by three manufacturers: Babcock & Wilcox, Foster Wheeler, and Riley Stoker. The wall-fired boiler, which is a major source of SO_2 and NO_x, has been the subject of the initial LIMB development because both the R&D background and large-scale experimental facilities were available.

Generalization of the Technology. To be widely accepted, a well defined set of criteria is necessary for application of LIMB to a wide range of boiler designs, coals, and sorbents. A limited number of demonstrations alone may not be sufficient for widespread private sector commercialization. A key element of the overall

program is to produce the required information and methodologies for applying LIMB R&D to site specific design decisions for any given boiler. This will be accomplished by a combination of modelling techniques and supporting measurements on operating boilers.

Status of the Technology

A recent EPA/EPRI symposium held in San Diego, California, provided a comprehensive overview of the R&D on LIMB and related dry injection technologies for SO_x and SO_x/NO_x control being performed worldwide. (ref 3)

There was substantial agreement on certain basic aspects of the technology; however, a number of technical areas require further work before the technology can be commercialized. Presentations covered the range from fundamental research to full scale boiler trials. In reviewing the technical data presented, certain categories of R&D were identified and grouped into technical areas. The LIMB portion of this paper is the EPA's technical summary and interpretation of the presentations and subsequent discussion.

Reaction Mechanisms. There was general agreement that the fuel rich chemistry (reduced sulfur compound) mechanism does not have a major role in sulfur capture under the conditions in pulverized coal fired systems. The reasons for this are not fully understood since the basic kinetics appear favorable. The mechanism for capture of reduced sulfur compounds under fuel rich conditions may be

studied further in the context of slagging combustors, where the solids are removed prior to the air addition for oxidation of partial combustion products.

The predominant mechanism for sulfur capture is the fuel lean capture of SO_2 in the upper reaches of the boiler. There was general agreement that SO_2 removal occurred in a temperature window of 982 to 1149°C (1800 to 2100°F) with a possible variance of 111 to 167°C (200-300°F) either high or low. The EPA considers the window to be between 871 and 1232°C (1600 and 2250°F). Note that the effects of residence time within that window were not entirely consistent, but probably within experimental/analytical bounds. In addition some question remains about the order of the reaction with respect to SO_2 as discussed below.

Coal Effects. The majority of the data tended to support the conclusion that the SO_2 capture is relatively independent of fuel sulfur content when it is above about 1 percent S. At lower sulfur levels the SO_2 capture efficiency tends to decrease due to a reduced gas phase driving force for diffusion. It is believed that a proposed apparent zero order in SO_2 concentration is due to a combination of the chemical kinetic rates and the intraparticle diffusion coefficients.

Sorbents -- Performance and Characterization. Data from EPA, EPRI, and DoE indicated that the reactivity of sorbents was related as follows: 1) dolomitic type sorbents [e.g., $MgCa(CO_3)_2$] are better

than calcitic [e.g., $CaCO_3$]; 2) hydrates [e.g., $Ca(OH)_2$] are better than carbonates [e.g., $CaCO_3$] for the same type alkali; 3) limestone [$CaCO_3$] alone is not likely to achieve LIMB performance goals; and 4) the unreactive magnesium (Mg) component of dolomite imposes an additional mass requirement that is not justified by current capture differential over calcitic materials. A number of issues relative to sorbents, which are unresolved at this time and require further work, are discussed below.

For sorbents the key technical and economic issue is the extent of calcium utilization. During the conference the reported range of utilization was from about 10 to 64 percent, depending on sorbent characteristics, system scale, and operating conditions. Many participants indicated that a calcium to sulfur ratio (Ca/S) of 2 was a likely maximum from the standpoint of solids loading and sorbent economics; however, for certain conditions (e.g., low sulfur coal) Ca/S = 3 to 4 might be considered. For 50 percent capture this requires a utilization of 25 percent at Ca/S = 2. Mass loading, total sorbent cost, and waste disposal cost all decrease as utilization increases. The closest thing to unanimity of opinion was that R&D should concentrate on increased utilization with 50 percent as a suggested goal. While the results reported show promise for improving utilization, further effort is required in the three aspects discussed below.

Surface area development and preservation. This is a key to

the reactivity of conventional sorbents. There is generally a good correlation between reactivity and surface area for a given class of sorbents; however, differences are observed between investigators when type is changed (e.g., $CaCO_3$ to $CaOH_2$). To date, a limited number of sorbents have been evaluated by any one investigator and, although overlap exists, different investigators have used different sources of similar type sorbents. One problem may be that a larger data base of sorbents characterized in a single facility is required. This should include characterization of activation and deactivation of a wide range of experimental and commercial materials including carbonates, hydrates, and oxides of both calcitic and dolomitic materials. Further investigation of production techniques is also required. Specific points are:

1. Surface area needs to be determined for both the starting material and the sorbent activated under a range of conditions. In addition to surface area more emphasis on pore size distribution should be considered.

2. The kinetics of calcination/dehydration/sintering need to be characterized for high temperature and short time typical of boiler injection of sorbents.

3. The effect of precalcination of limestone to calcium oxide on reaction in the furnace needs to be examined

more thoroughly. Additional process aspects of calcination to produce high surface areas require further work.

4. The effects of hydration conditions on sorbent properties should be emphasized especially for calcitic materials. The effects of initial lime properties on hydrate characteristics and the differences between atmospheric and pressure hydrates must be quantified.

Role of promoters. The use of relatively small quantities of minerals (e.g., sodium compounds) to increase the activity of conventional sorbents for in-furnace SO_2 removal was discussed, predominately by EPA inhouse and contract researchers. There was considerable interest in this development; however, a better understanding of several aspects is necessary to assess its applicability to practical systems, including:

1. The mechanism of the promotion of reactivity must be established. Current data suggest that different mechanisms may exist for different classes of promoters. The speculations include: modification of ionic diffusion in the particle product layer; fluxing of the surface, leading to faster liquid phase diffusion; stabilization of surface area; and catalysis of SO_2 to SO_3.

2. The optimum conditions for promoter/sorbent contacting must be established. The possibilities include: injection together or separately; injection of the promoter at a

higher temperature than the sorbent; avoidance of scavenging of the promoter by fly ash; and incorporation of the promoter in the sorbent at the time of production (e.g., hydration).

3. The interaction of a promoter with the sorbent surface area needs to be understood. The early data with chromium oxide suggested substantial promotion of limestone reactivity and high sorbent utilizations. This occurred even at thermal conditions where measurements of the same sorbent without promoters showed very low surface areas. There are also small scale data that suggest that sodium promoters actually decrease surface area yet increase reactivity. For high surface area sorbents (e.g., hydrates), conditions expected to preserve surface area appear to be beneficial.

4. The role of magnesium in dolomitic sorbents still needs to be established. Its role may be attributable to mechanisms similar to those discussed above, but physical mixtures of $MgCO_3$ and $CaCO_3$ do not show a promotion of SO_2 reactivity.

Sorbent fundamentals. The body of evidence to date does not show a clear relationship between the properties of different starting material (e.g., limestone petrography) and the characteristics (e.g., surface area) of the resultant calcine

under comparable conditions. A continuing effort to identify a first principles relationship is necessary. In the absence of such a correlation, a uniform procedure for screening new materials needs to be established.

Injection Technique. There was also general agreement that good mixing of the sorbent with the combustion gases is essential to good SO_2 capture. Most of the investigators concluded that upper furnace injection was superior to injection through the burner; however, there was one important exception, discussed later. In addition, there was general agreement that this area needs more attention in the R&D and field application programs.

Any sorbent injection technique must produce rapid and uniform mixing of the sorbent with the combustion gases. Injection through or around the burner is ideal from a mixing standpoint; however, it has the disadvantage of sorbent deactivation due to high temperature and/or ash interactions. Downstream injection solves most of the deactivation problems but requires more attention to injector design location to achieve good mixing and high reactivity. Note that different sorbent types (e.g., high surface area versus promoted materials) may require different injection approaches.

Most of the data presented indicated that injection downstream of the burner gave improved SO_2 capture efficiency. This appeared to be consistent both for small systems, where mixing is not a major constraint, and for larger scale systems [e.g., EPA's large

watertube simulator (LWS) firing at 30 MW thermal] where injection design and sorbent mixing is more of a factor. The exception to this was the Foster Wheeler/Conoco data from a prototype scale experimental facility and an industrial boiler which appeared to show improved capture with a proprietary "inburner" injection scheme using a limestone sorbent. Note that, for a number of burners tested in the LWS, the burner design appeared to have only a minor effect on sulfur capture for sorbent injection at the same location (e.g., with the fuel or the tertiary air). Sorbent type and injection location had greater effects. Further work is planned to evaluate additional burning zone and upper furnace injection configurations; however, the conclusion at this point is that the design of the low NO_x burner is not the critical element in determining the SO_2 capture achieved. Most boiler applications of sorbent injection appear to be moving toward downstream sorbent injection. A number of issues remain to be solved, including:

1. Injection and mixing systems or approaches must be identified which give satisfactory distribution of the sorbent into the combustion gases at the proper location in the boiler. This must take into account the gas flow and temperature stratifications which occur in practical boilers and provide for mixing over large cross sections.

2. Once the sorbent and carrier fluid are injected, the interaction and subsequent mixing with combustion gases and simultaneous calcination/dehydration of the sorbent must be

quantified. Critical loss of sorbent reactivity can occur during this transition period.

3. The thermal impact of the carrier fluid on boiler operation must be assessed. If a significant percentage (i.e., 10-15 percent) of the boiler gas flow must be used to inject the sorbent, the impact on thermal efficiency will be significant. Techniques must be developed which minimize this effect.

4. The access to the boiler in the desired location may be limited by physical factors, which is a boiler and site specific variable. Techniques must be developed to accommodate design limits identified in process analysis studies.

Impact of Sorbent on Boiler and ESP Operation. As previously mentioned there is a limit on the incremental solids loading which can be passed through the boiler and electrostatic precipitator (ESP). The solids loading governs a number of potential problems including slagging, fouling, erosion, convective pass and air heater plugging, ESP performance, and waste handling and disposal. Many of these subjects were discussed in technical presentations and were a major topic of the panel discussion. Specific topics which must be addressed are:

1. The presence of calcium alone can impact the slagging and fouling tendency of the boiler. Most evidence suggested that

deposits during sorbent injection were heavier than conventional ash deposition but were also easier to remove with soot blowers.

2. The effect of sodium (e.g., used as a sorbent promoter) on ash characteristics produced conflicting statements. It is well known that coals (especially lignite and subbituminous) which contain significant amounts of inherent sodium have strong slagging and fouling tendencies. The main boiler effect is in fouling where sodium volatilized during coal combustion subsequently deposits as a liquid layer on convective tube surfaces and promotes accumulation of fly ash deposits. It is also well known that the addition of calcium may beneficially raise ash fusion temperature and decrease fouling tendencies. Data for a sodium containing subbituminous coal show a reduction in ash bonding strength from 30 (very strong) to 8 (easily removable) by the addition of calcium carbonate. However, there were also concerns that addition of a small amount of sodium as a promoter to a calcium based sorbent will significantly <u>increase</u> slagging and fouling. This apparent inconsistency needs to be resolved.

3. The presentations suggested that furnace heat transfer could be adversely affected in two ways. The most straightforward effect was decreased heat transfer due to deposits on heat transfer surfaces. It also indicated that the deposits could be controlled and heat flux maintained by soot blowing.

The second effect is that in a larger boiler (e.g., >300 MW electric) the increased solids loading may decrease radiant heat transfer to the water walls and thereby increase exit gas temperature. Note that the European boilers, especially lignite and brown coal fired, for which data were available have larger furnace volumes than most U.S. boilers of comparable capacity. This may suggest that the effect, if it occurs, might occur at a larger boiler size in the U.S.

4. The increased solids loading, increased ash resistivity, and possible shift in particle size distribution can all impact the performance of the ESP. Since increasing the specific collector area (SCA) of an existing ESP is difficult, other solutions were examined. Bench scale data suggest that the resistivity question can be resolved either with SO_3 conditioning or with humidification of the flue gas. The Conoco presentation suggested that humidification plus pulsed power could restore the performance of a marginal size ESP at the industrial boiler. The EPA program provides for pilot scale ESP testing of these conditioning options alone or in connection with retrofittable hardware (e.g., prechargers). This approach applies existing technology to the solution of LIMB particulate problems and does not involve developing new ESP technology.

5. Finally, the data indicated a near total removal of SO_3 from the flue gas which has two effects. First, it can lower

the effective particulate loading in the stack by eliminating the particulate sulfate component. Second, it may allow some cold end heat recovery which would tend to increase system efficiency according to an EPRI analysis.

Waste Disposal. In the past the disposal of waste material has received limited consideration due to the undefined nature of the product from sorbent injection into a boiler. During the conference, major concern was expressed concerning the fate and handling of the unreacted CaO in the waste. A particular concern was the high levels of alkalinity observed during recent tests (e.g., Conoco). In addition solubility of the waste was raised as a problem particularly if sodium compounds were present. Extensive treatment of the waste would adversely affect the economics of the process, if it were required. Note that this is directly related to the efforts to improve sorbent performance, since increased sorbent utilization automatically reduces both the mass of sorbent and the amount of free CaO in the waste.

The LIMB program is considering waste disposal and/or utilization as a part of the engineering analysis activity. Emphasis is being placed on recycle of unreacted sorbent to improve utilization in the boiler and on post collection utilization of the material to achieve a byproduct credit. Preliminary cost analysis indicates that simply eliminating disposal expense, which was assumed to be equivalent to that for fly ash, has significant economic benefits. Additional effort will be devoted to technical and economic aspects

of disposal, recycle, and/or utilization of the unreacted CaO.

Economic Analysis. While some preliminary economic analyses have been conducted on LIMB and its comparison to FGD, uncertainties are unavoidable at this stage of development of the technology. The process requirements are not completely defined and, even when they are, site specific factors may play a dominant role in any given application. In addition, many of the R&D issues cited above (e.g., utilization, waste disposal) may have significant positive or negative impacts. For these reasons the future of the technology can not be determined based on cost analyses until R&D and several actual boiler applications are completed.

Applicability of LIMB. The extent of applicability of LIMB was raised at the panel discussion. The answer to the question depends on both policy and technical questions which are not resolved at this time. It is well known that the extent of control of SO_2 has been debated over a wide range -- from 4.5 to 10.9 x 10^9 kg per year (5 to 12 million TPY) -- and a mandate of FGD for some number of the largest sources has been proposed in at least one bill. It is not known if a bubble approach for a system or an individual unit basis will be allowed. The issue of an NO_x offset is not settled. All of these factors will affect the efficiency required for retrofit SO_2 control technology. In addition, it is not known if a low sulfur coal switching strategy, which is potentially attractive for moderate SO_2 control (i.e., 50 percent), is socio-economically acceptable or logistically possible (e.g., railroad

capacity). Finally, the current rapidly evolving state of development of LIMB does not allow an authoritative evaluation of its practical and economic viability.

Based on current analysis of cost, a number of factors impact the relative cost of LIMB at 50-60 percent SO_2 control versus FGD at 70-90 percent. These differences are caused by the fact that LIMB is an operating cost driven technology while FGD is driven more by capital cost. The EPA inhouse computer model indicates that the dominant factors are: 1) sorbent utilization efficiency; 2) sorbent cost; 3) remaining useful boiler life; 4) capacity factor; and 5) coal sulfur content. For constant values of the first two items, LIMB is favored by shorter boiler life (15 years or less); lower boiler load factor (less than 62 percent); and for lower sulfur coal (less than 2.5 percent). However, in the final analysis the technical and economic applicability of LIMB cannot be definitized until one or more successful demonstrations are completed.

LIMB Program Research and Development Plans

This section discusses the R&D plans for each of the four major program areas discussed in the program description above. This R&D covers most of the unresolved issues identified in the discussion of technical status.

Generic R&D. The LIMB program has been based on the fact that a complete understanding of the process is necessary to give the

maximum probability of successful commercialization by the private sector. Generic R&D is relatively independent of the hardware-specific constraints of practical boilers and provides information essential for application of LIMB to all boiler designs. This section provides a brief description of the current status, followed by a detailed discussion of plans for FY85 and following years.

Current status. The R&D has provided an excellent insight into the effects of critical process parameters on SO_2 capture. It has shown how these parameters affect sorbent activation and subsequent sulfur capture as a function of combustion system conditions. It has also provided an understanding of fly ash/sorbent mixture characteristics as related to particulate capture. As a result of these findings, it has been concluded that limestone alone will not achieve the LIMB sulfur capture goals for many units in the U.S. boiler population. However, it has also provided at least two alternate sorbent approaches capable of meeting or substantially exceeding the goal of 50-60 percent capture. These approaches, which are high surface area sorbents and promoters to enhance sorbent activity, are discussed below.

Major generic R&D areas. The continuing small-scale R&D needs are divided into three major areas:

1. Inhouse research has identified high surface area sorbents as a key factor in obtaining high efficiency sulfur capture.

It has been shown that high surface area can be generated external to the combustion process and/or after injection into the boiler. These materials, which are processed limestone (e.g., hydrates), have shown the potential for sulfur capture in excess of 70 percent. The planned R&D addresses methods for obtaining high surface area sorbents, for optimizing reaction conditions to achieve maximum capture, and for minimizing sorbent costs.

2. Another key factor is the interaction of sorbents with mineral matter which can either enhance or degrade the sorbent reactivity. The most promising results indicate that it may be possible to add small amounts of relatively inexpensive, innocuous promoters (mineral compounds) which will enhance the sorbent activity. Sulfur captures approaching those of high surface area sorbents have been achieved with promoted limestone in limited bench scale experiments. It also appears that promoters can significantly improve the performance of high surface area sorbents (e.g., hydrates). A significant effort is in progress to understand the enhancement mechanisms and to provide the basis for use in practical systems. A similar understanding is necessary for other sorbent/mineral matter interaction which can inhibit sulfur capture and which affect slagging, fouling, and collection characteristics of the particulate.

3. Process analysis has indicated substantial benefits may be derived from recycle of unreacted sorbent and promoters. In addition, utilization of the spent sorbent and fly ash has significant potential economic benefits. The engineering feasibility of these process options for recycle, utilization, and/or disposal is being evaluated.

Prototype Testing. Extensive prototype testing of wall-fired boiler low-NO_x burners has been conducted to evaluate sulfur capture potential with injection of conventional sorbents. A substantial data base exists for both NO_x and SO_x control potential of a number of experimental and commercial burners. Any additional work will be in support of site specific decisions for the wall-fired demonstration.

The emphasis has been shifted to tangentially fired prototype systems and to use of improved sorbents, which are identified in generic R&D, for all systems. Tangential prototype work will be initiated in a large-scale experimental facility with a firing system producing a vortex flow field typical of that boiler class. In addition, a cooperative testing R&D program will be conducted on a small boiler (20-40 MW) to evaluate sulfur capture potential, operability, and reliability over short periods with fuel and sorbent flexibility. The prototype work will concentrate on evaluation of optimum sorbents and injection methods to maximize SO_2 capture and on effects of sorbent injection on boiler and particulate control system operability and reliability.

Wall-fired Demonstration. The contract for the wall-fired demonstration was awarded in September 1984, to Babcock & Wilcox Company. LIMB will be installed on a 105 MW singlewall-fired unit at the Edgewater No. 4 station of Ohio Edison Company. The final site specific design for the installation will be completed in February 1986. Long term testing over a 1 year period will begin in July 1987, and a report documenting the performance evaluation will be completed late in 1988.

Technology Generalization. For ultimate widespread use of the LIMB technology, the R&D results must be integrated with the full-scale boiler demonstration results to provide guidance for commercialization by the private sector. The program includes: 1) process analysis to evaluate applicability and economics for specific systems; and 2) process modelling to provide a methodology useful for site specific designs. The process analysis emphasizes LIMB system options for application to different boiler classes in the population and for minimizing the cost per unit SO_2 removal. The process modelling will provide component models for thermal history, sorbent activation and reaction, injection, and mixing.

E-SOX PROCESS

EPA's AEERL has begun theoretical and experimental work to combine advanced electrostatic precipitation (ESP) and SO_2 removal technologies in an existing ESP. This process, called E-SOX, combines advanced ESP technology and spray dryer technology to remove

particulate and SO_2 in the same physical equipment.

Advanced ESP technology provides the means for collecting particles with high efficiency in relatively small ESPs. The technology can be used to reduce the required size of new ESPs or to free space in an existing ESP that can be used to collect SO_2. This ESP technology is described in greater detail in reference 4.

Conceptual Design

The basic idea of E-SOX is to turn an existing ESP into a combination spray dryer and advanced ESP. (ref 5) The conceptual design can best be understood by considering a hypothetical ESP used to control particulate emissions from a boiler firing high sulfur coal. The following modifications, shown in figure 2, would convert the ESP to E-SOX:

1. Remove the wires and plates in electrical section 1.
2. Install a bank of spray nozzles at the inlet of electrical section 2. These nozzles should produce fine drops with diameters between 15 and 30 μm.
3. Install prechargers (either cooled pipe or other design) at the inlet of sections 2 and 3.
4. Replace the normal discharge electrodes in sections 2 and 3 with large diameter wires.

The removal of wires and plates in section 1 provides a space

for SO_2 removal. At typical gas velocities in an ESP (1 to 2 m/sec), section 1 would provide about 1.5 to 3.0 sec residence time for SO_2 removal and drop evaporation.

The precharger and large diameter wires added to sections 2 and 3 convert the remainder of the ESP from single- to multi-stage. This conversion will compensate for the reduction in SCA from 41.3 to 27.5 sec/m. As discussed later, this multi-stage ESP configuration makes it possible to meet the 43 ng/J particulate emission standard assumed for the plant.

The design goal for the E-SOX system is continued compliance with the particulate emission limits of 43 ng/J for the plant and 50 to 60 percent SO_2 removal. A particulate emission standard of 43 ng/J is typical of the particulate emission standards required of most existing power plants.

Experimental

The experiments were conducted in AEERL's in-house ESP pilot plant. The pilot ESP is a four-section single-lane pilot plant capable of operating from ambient to 350°C. Sampling ports are located at the ESP inlet, the ESP outlet, and between each pair of electrical sections of the ESP.

The configuration for these experiments is shown in Figure 3. Sections 1 and 2 were converted to SO_2 reaction chambers by removing the wires. The SO_2 was injected at point A located before the

gas distribution plate. Scrubbing liquid was injected at point B using two sonic spray nozzles. These nozzles are two-fluid (air, slurry) nozzles and produce drops of 5 to 10 μm in diameter. SO_2 was measured at four locations (C, D, E, and F). Location C provided about 0.5 sec of residence time; location D, 1.3 sec; location E, 2.1 sec; and location F, 3.7 sec. For the E-SOX tests the pilot plant was operated with a gas inlet temperature of 150°C and a gas flow rate of about 0.487 am^3/sec at 150°C.

Results

Two sets of experiments were conducted: sodium carbonate was used as the scrubbing reagent for the first set; and lime was used for the second. The experimental procedure was the same for both sets of experiments. SO_2 readings were made at all sampling locations with the scrubbing liquid off. The scrubbing liquid was turned on and the system allowed to come to steady state. Then SO_2 measurements were made, and the scrubbing liquid was turned off. The SO_2 measurements were than repeated. For a typical run the maximum difference between the two scrubbing-liquid-off measurements was less than 20 ppm; i.e., the inlet SO_2 concentration varied by less than 20 ppm. A summary of the results is presented in Figure 4 and discussed below for each reagent.

Sodium Carbonate. The upper band of data in the figure shows the performance with sodium carbonate. For a given residence time the range of sulfur capture shown is a function of slurry drop size and

sorbent to sulfur stoichiometry. The bulk of the SO_2 removal (e.g., 50 percent) was achieved in the first 0.5 second of residence time; however, the reaction continued at a lower rate up to 3.7 seconds. The high reactivity is achieved while the sorbent is present in the liquid phase. After the droplets of slurry evaporate the rate of reaction for the dry solid drops sharply. This represents an opportunity for optimizing the technology by achieving the longest droplet evaporation time consistent with presenting a dry particulate to the active ESP sections.

Hydrated Lime. Because the results with sodium carbonate were encouraging, experiments were conducted using hydrated lime as the alkaline material. A slurry of lime and water was injected through the same nozzles used during the sodium carbonate experiments. The results of the lime experiments are summarized by the lower band in Figure 4. The particular lime used in these experiments was not reactive enough to allow measurable SO_2 removal after the lime particles became dry. This indicates that the major advantage of sodium carbonate as compared to lime is the high reactivity of the dry sodium carbonate particles. Some of the highly reactive limes, being studied in conjunction with other retrofit SO_2 removal systems, may increase the SO_2 capture efficiency of E-SOX with lime to near the levels obtained with sodium carbonate.

The experimental data for both lime and sodium carbonate show that the design goals of the E-SOX system can be achieved with either reagent. A residence time of 1 sec is sufficient for 60

percent SO_2 removal with E-SOX and lime.

Particulate Collection. E-SOX's success depends on its ability both to provide 50-60 percent SO_2 removal and to meet particulate emission limitations. Therefore, experiments were conducted to simulate the particulate collection of an E-SOX ESP. In these experiments lime slurry was injected through the spray nozzles. Fly ash was injected through sand blast guns, as is normal for the operation of the pilot plant for fly ash experiments. The ESP was converted to multi-stage configuration with cold-pipe prechargers installed in sections 1 and 3 and large wires installed in sections 2 and 4. The SCA of the ESP for these tests was about 11 sec/m. The results of the experiments were input to the particulate model which predicted that the particulate goal of 43 ng/J could be achieved with an SCA of about 24 sec/m.

R&D Plans

Research is continuing to improve and verify the SO_2 and particulate removal models for E-SOX. Also a series of in-house experiments with the entire system of SO_2 removal and multi-stage ESP was planned for early 1985. A large pilot scale evaluation of E-SOX may take place in 1986.

Research is also planned to reduce the amount of lime required for a given level of SO_2 removal. Reducing the amount of lime reduces the particulate burden on the multi-stage ESP and can significantly reduce the capital and operating costs of the system.

SUMMARY

The LIMB R&D program has provided a detailed understanding of the key processes governing sulfur capture with sorbents. While it appears that limestone alone will not achieve program goals, several other promising sorbents have been identified. Based on the R&D results and cost estimates of the use of these sorbents, LIMB shows substantial promise as a SO_x and NO_x control technology for retrofit applications. The ongoing R&D program should resolve the remaining technical questions and provide a basis for widespread private sector commercialization.

The experimental data and the modelling based on that data show that E-SOX is capable of providing 50-60 percent SO_2 removal in an existing ESP while meeting a particulate emission standard of 43 ng/J. Further R&D is necessary to optimize SO_2 capture and to scale the technology up to a practical size. E-SOX has the potential to be an economically attractive emerging method of SO_2 control.

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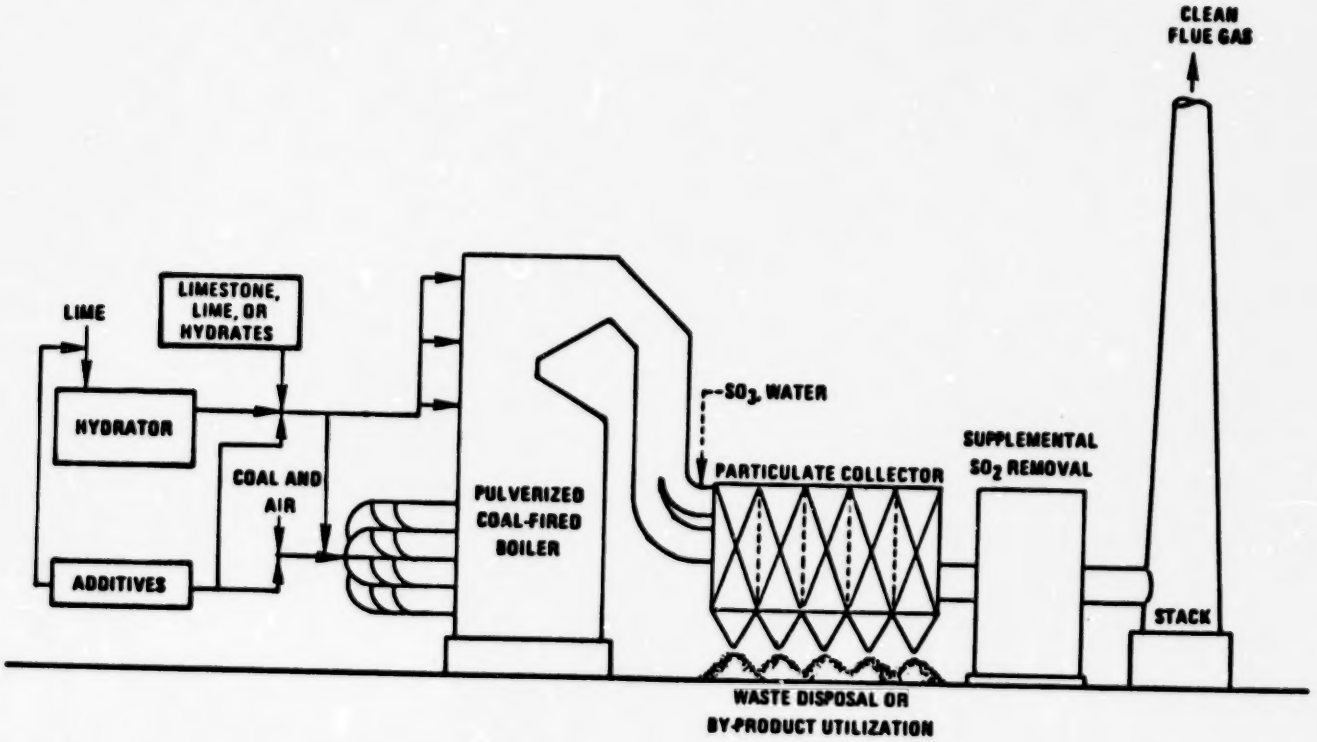

Figure 1. Schematic of Integrated LIMB System

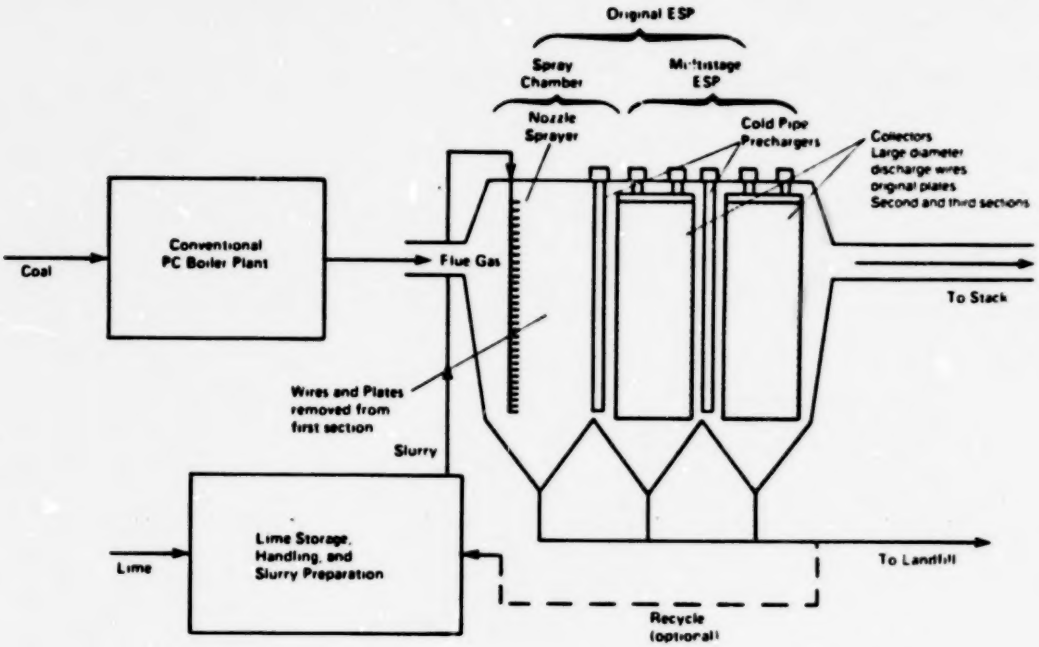

Figure 2. Schematic of E-SOX Process

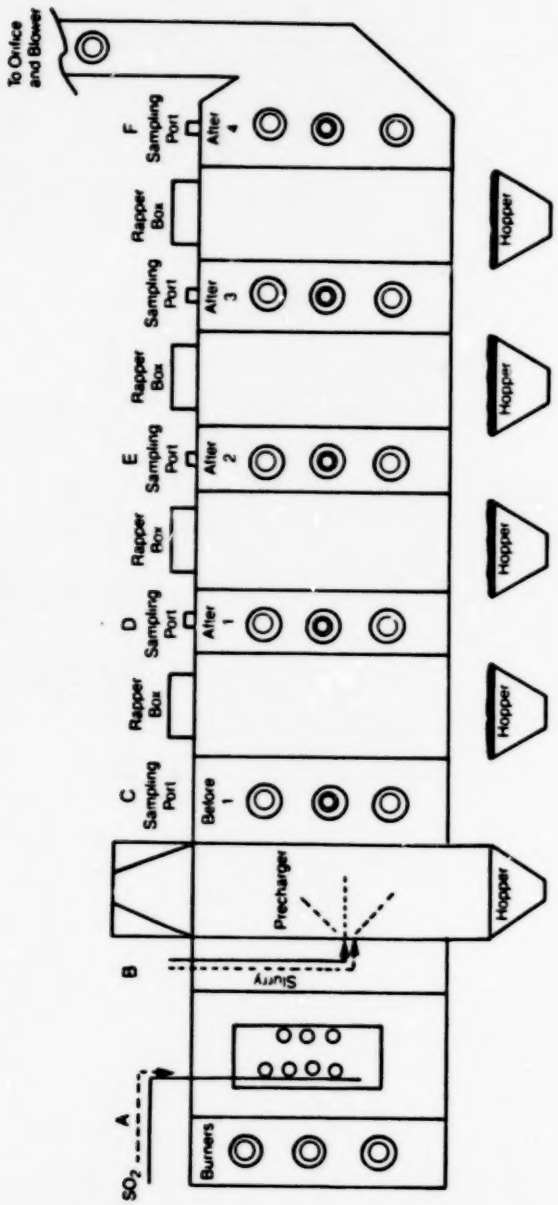

Figure 3. Sketch of Pilot Plant Modified for E-SOX

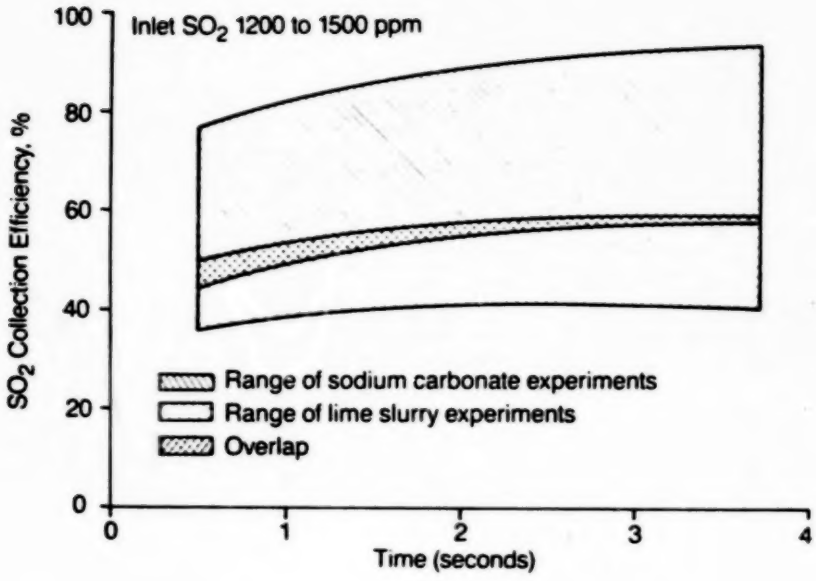

Figure 4. E-SOX Data for Sodium Carbonate and Lime Slurry Experiments